(12) UK Patent Application (19) GB (11) 2 112 579 A

(21) Application No 8127439
(22) Date of filing 10 Sep 1981
(43) Application published 20 Jul 1983
(51) INT CL³ H01Q 9/16
(52) Domestic classification H1Q DP HC
(56) Documents cited GB 1307496 GB 1182952
(58) Field of search H1Q
(71) Applicant
National Research Development Corporation (Great Britain)
Kingsgate House
66–74 Victoria Street
London SW1E 6SL
(72) Inventor
Maurice Clifford Hately
(74) Agent and/or Address for Service
C Hasler
101 Newington Causeway
London SE1 6BU

(54) Multiband dipoles and ground plane antennas

(57) Quarter wavelength conductors W, Fig. 1, resonating in pairs constitute multiband dipole radiators whose impedance and electrical balance are produced by means of a simple arrangement of phase shifting capacitors C at the central coaxial feed point. Analogous multiband ground plane forms Fig. 7 derived therefrom are unbalanced but valuable in practice.

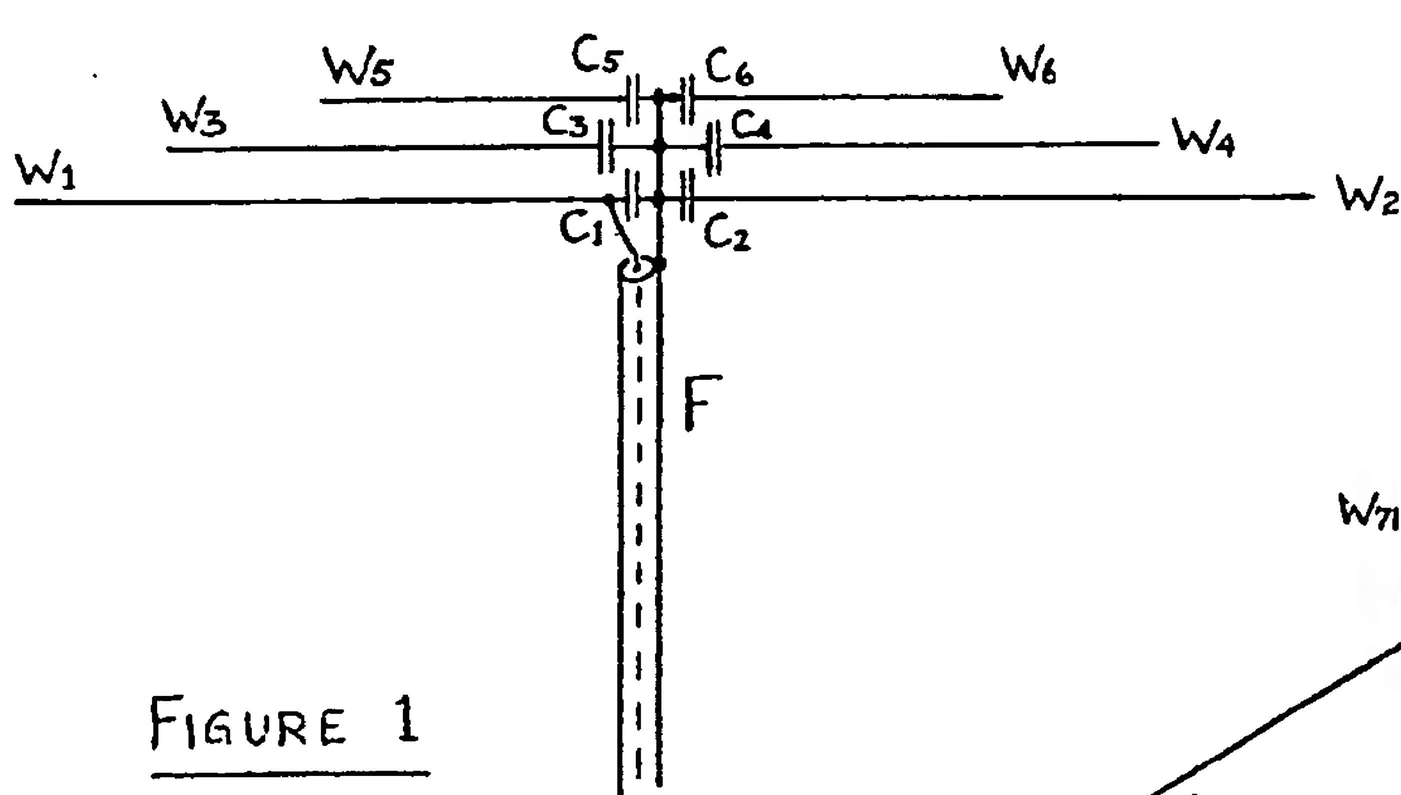

FIGURE 1

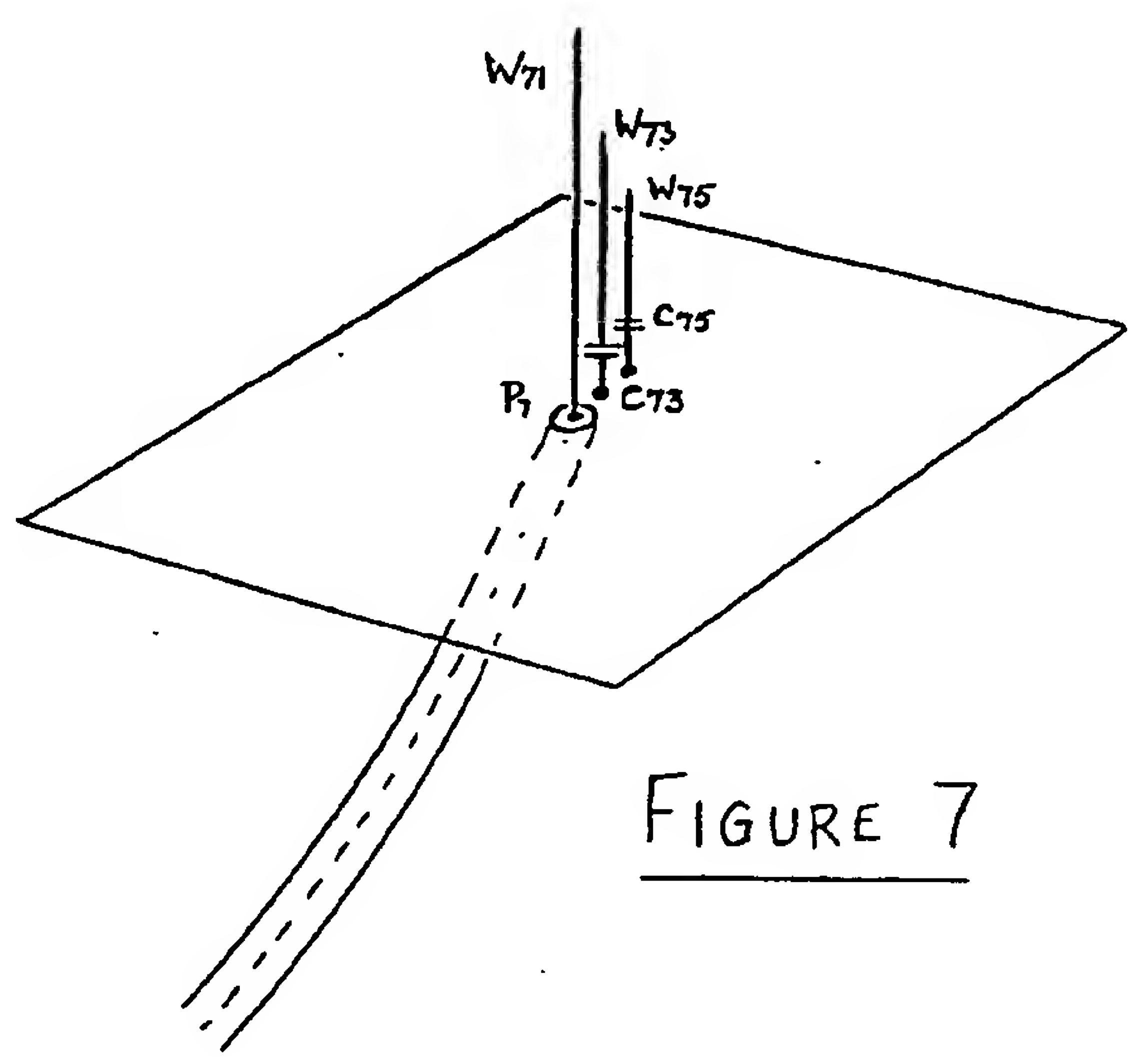

FIGURE 7

GB 2 112 579 A

BEST AVAILABLE COPY

2112579

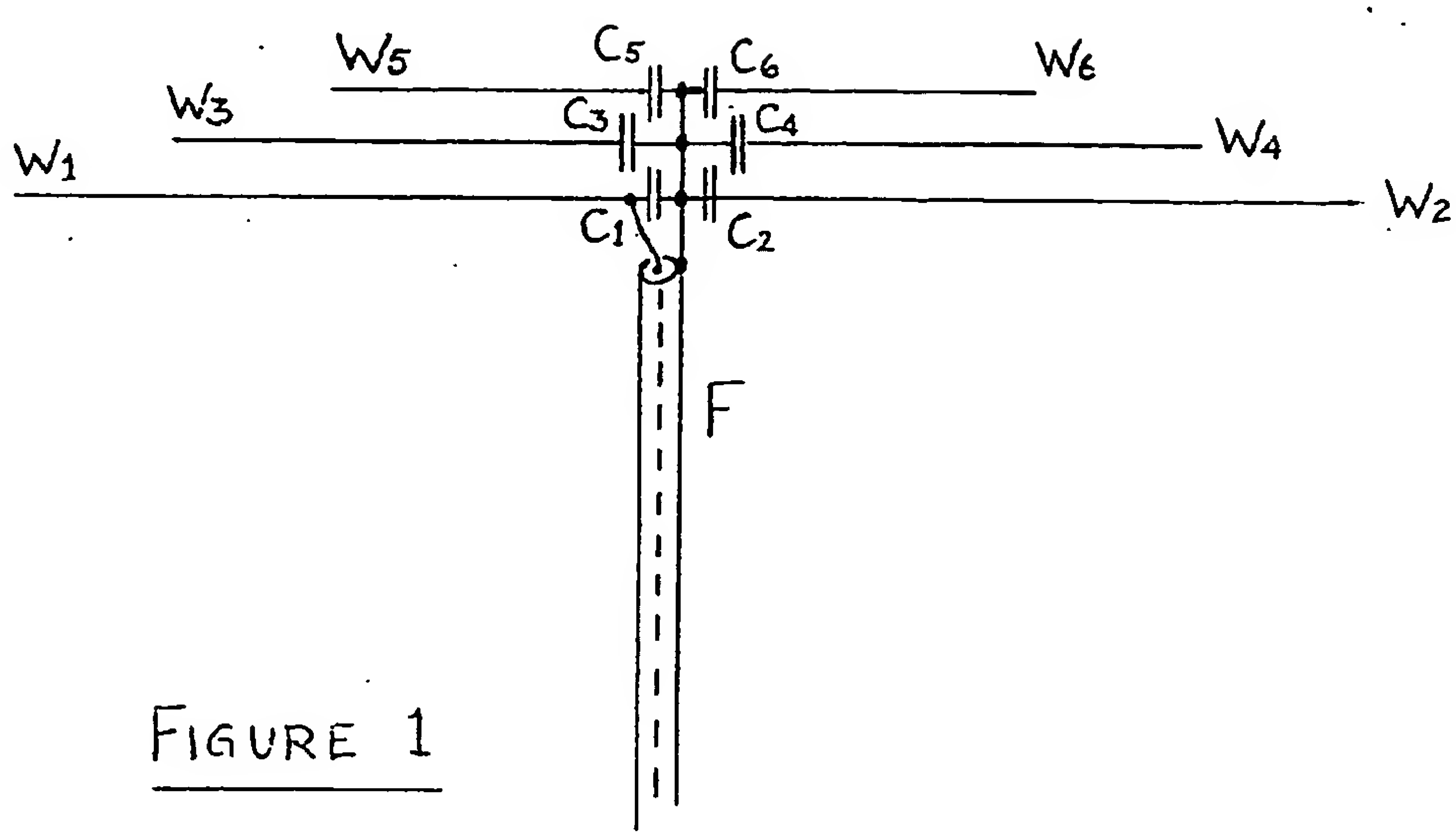

FIGURE 1

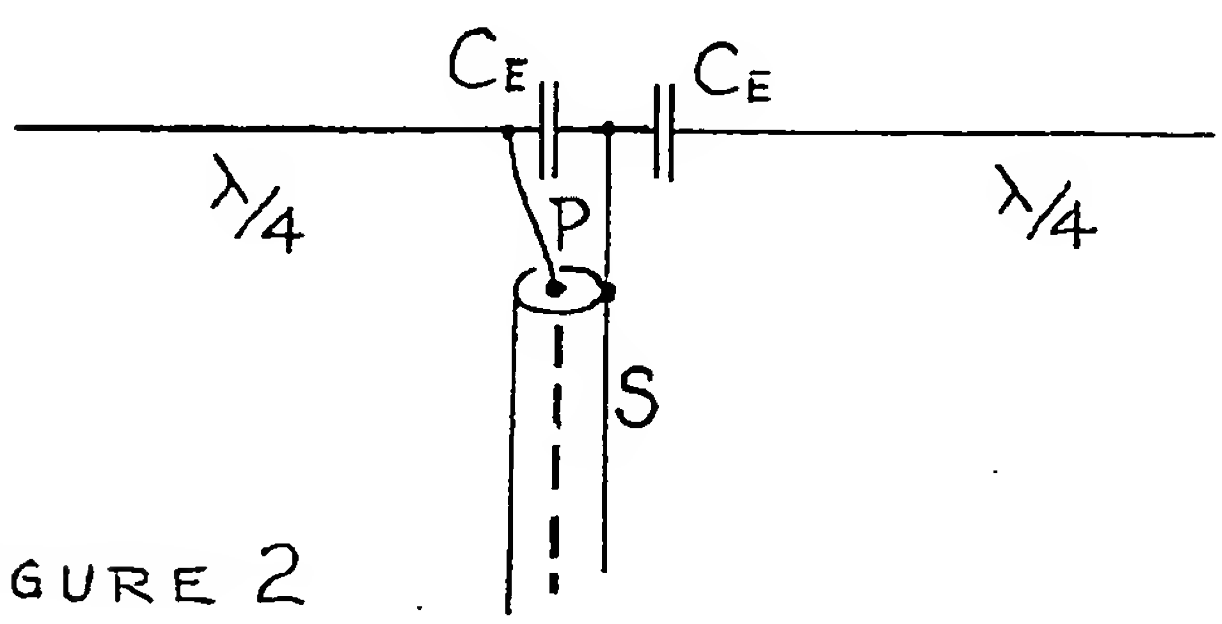

FIGURE 2

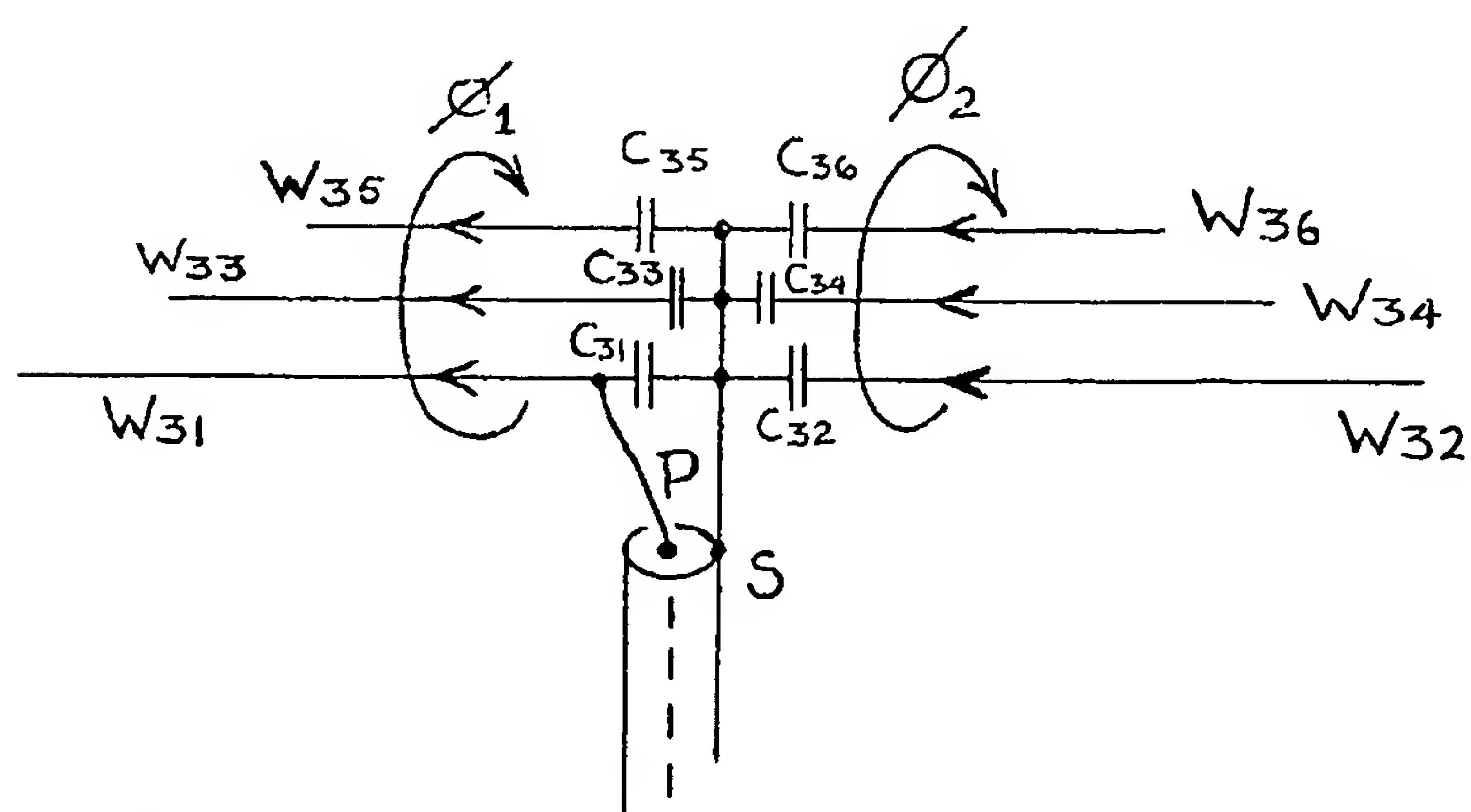

FIGURE 3

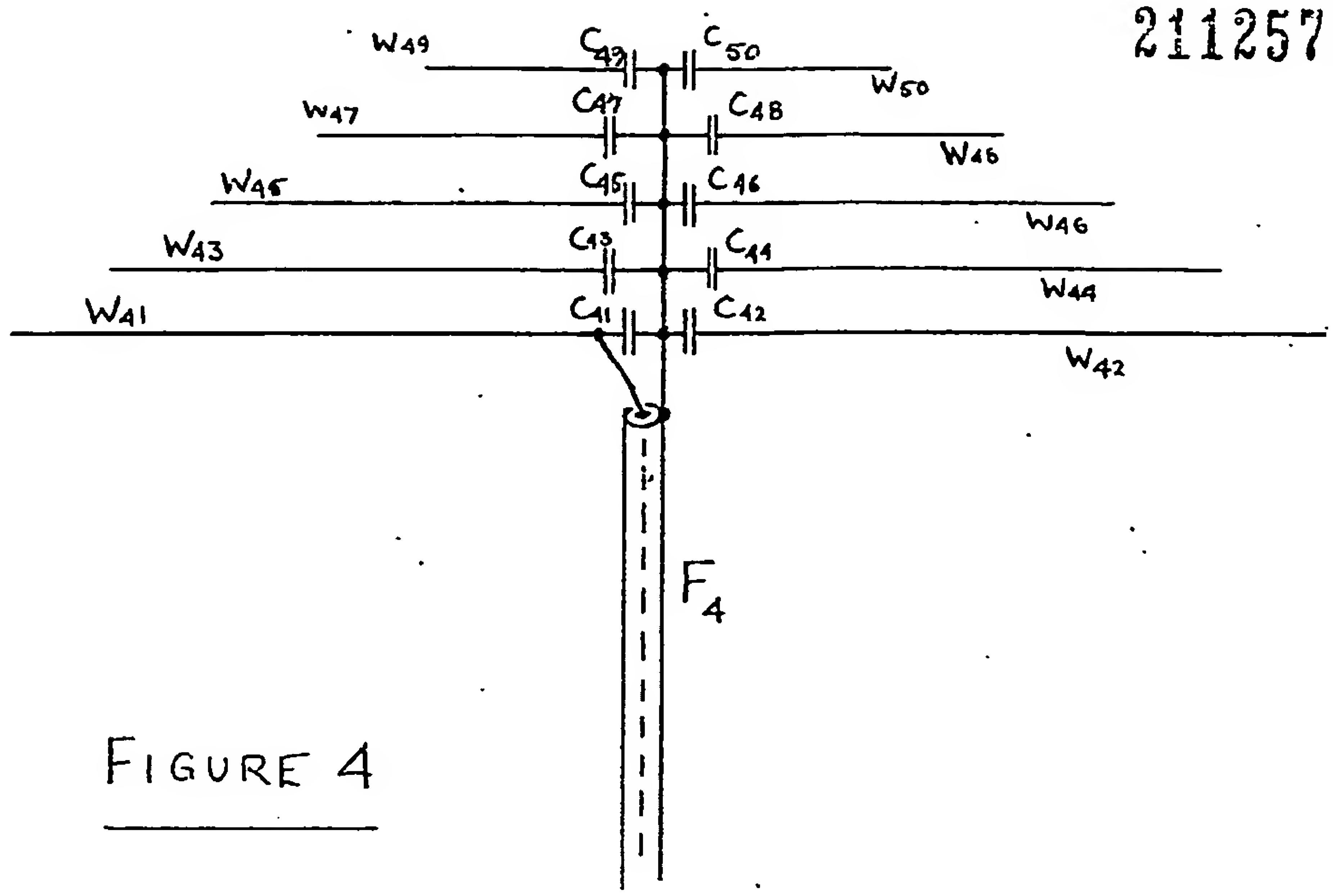

FIGURE 4

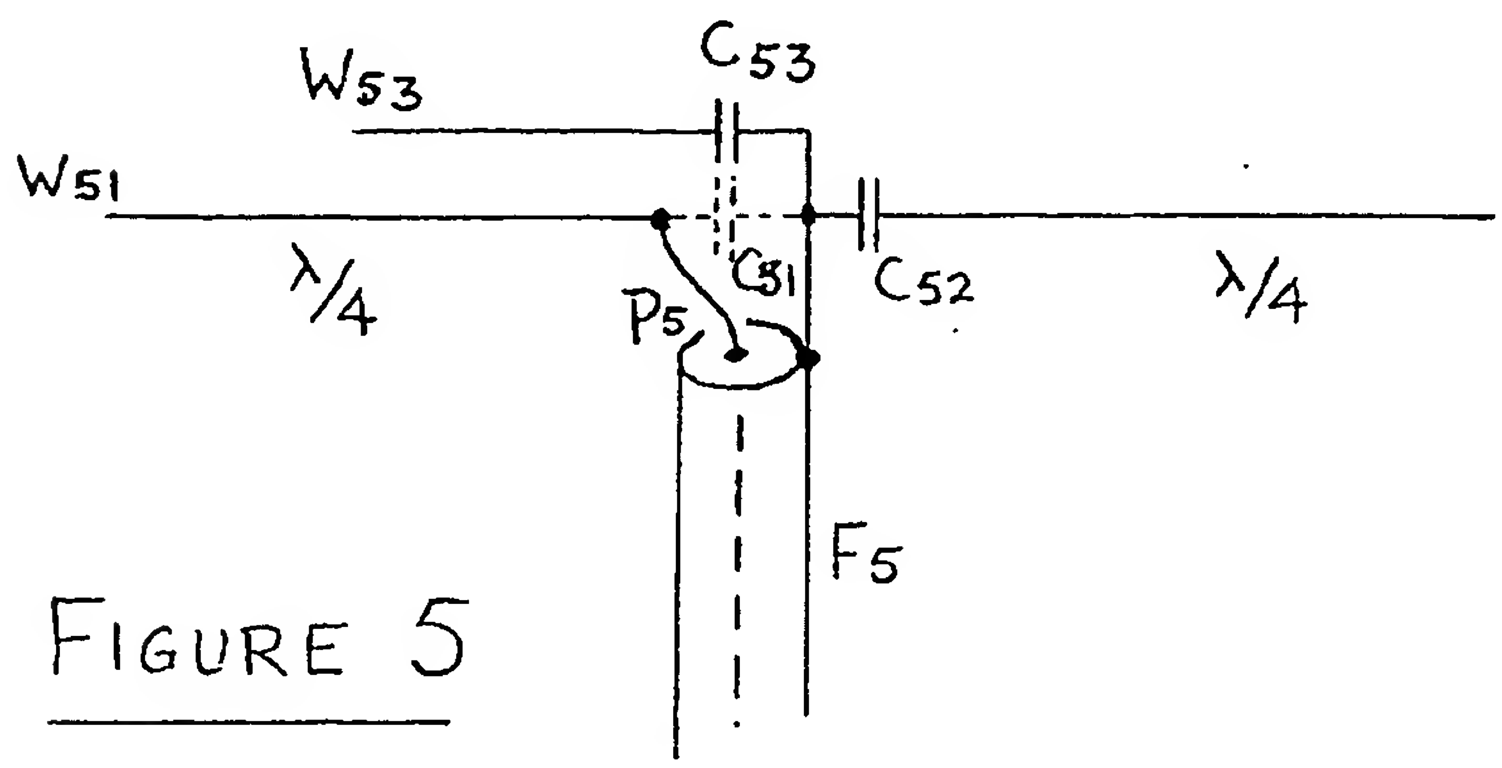

FIGURE 5

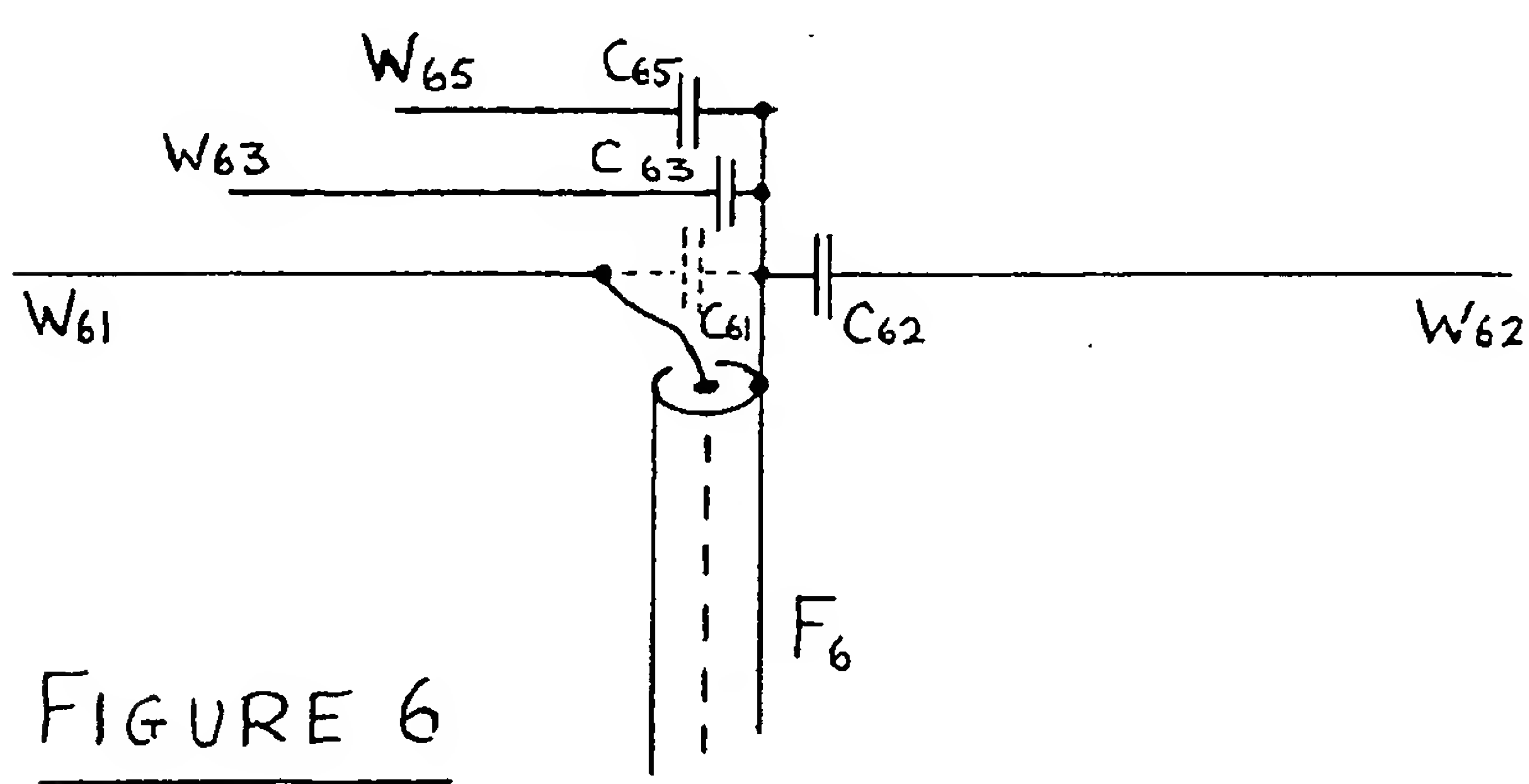

FIGURE 6

2112579

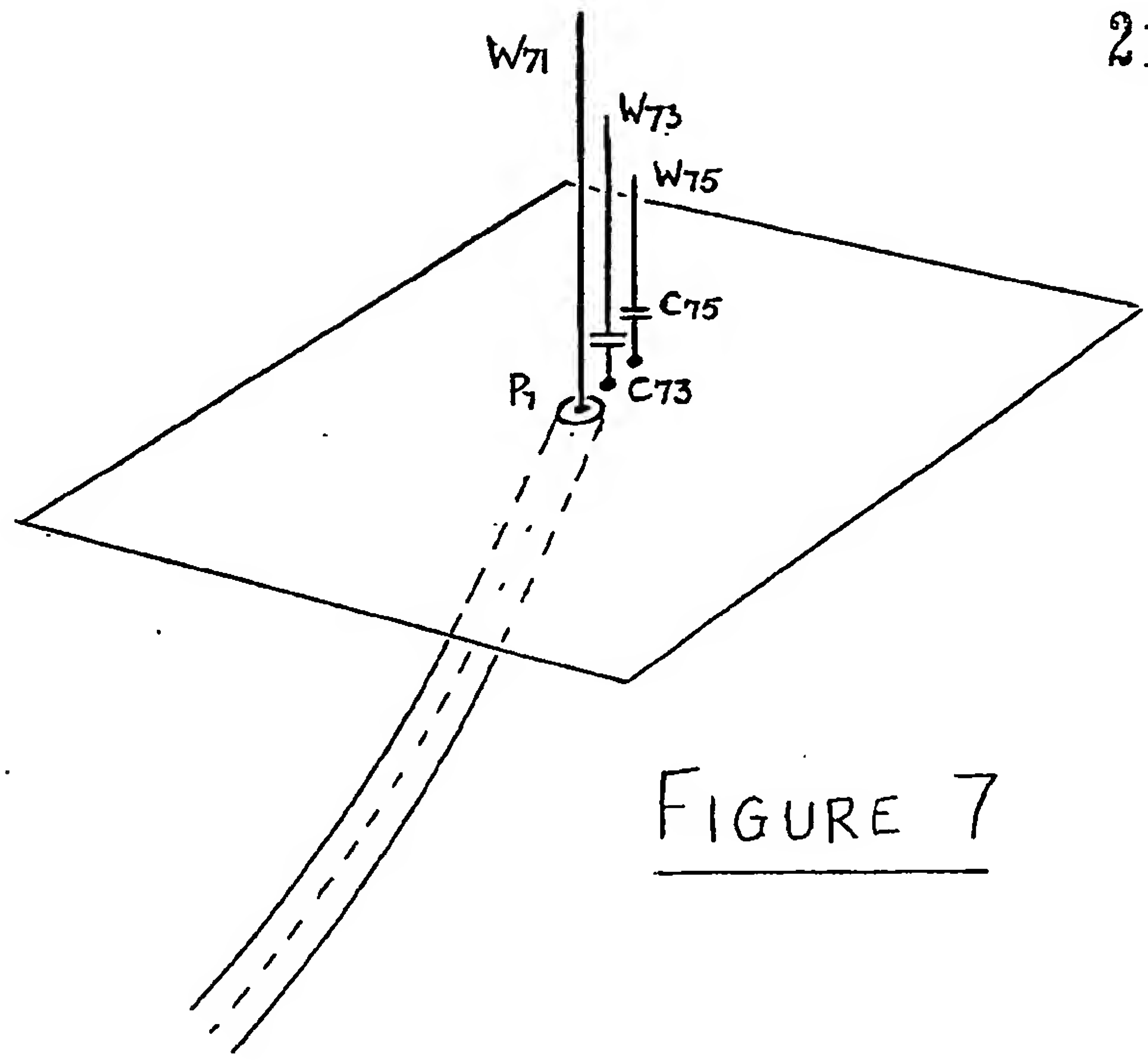

FIGURE 7

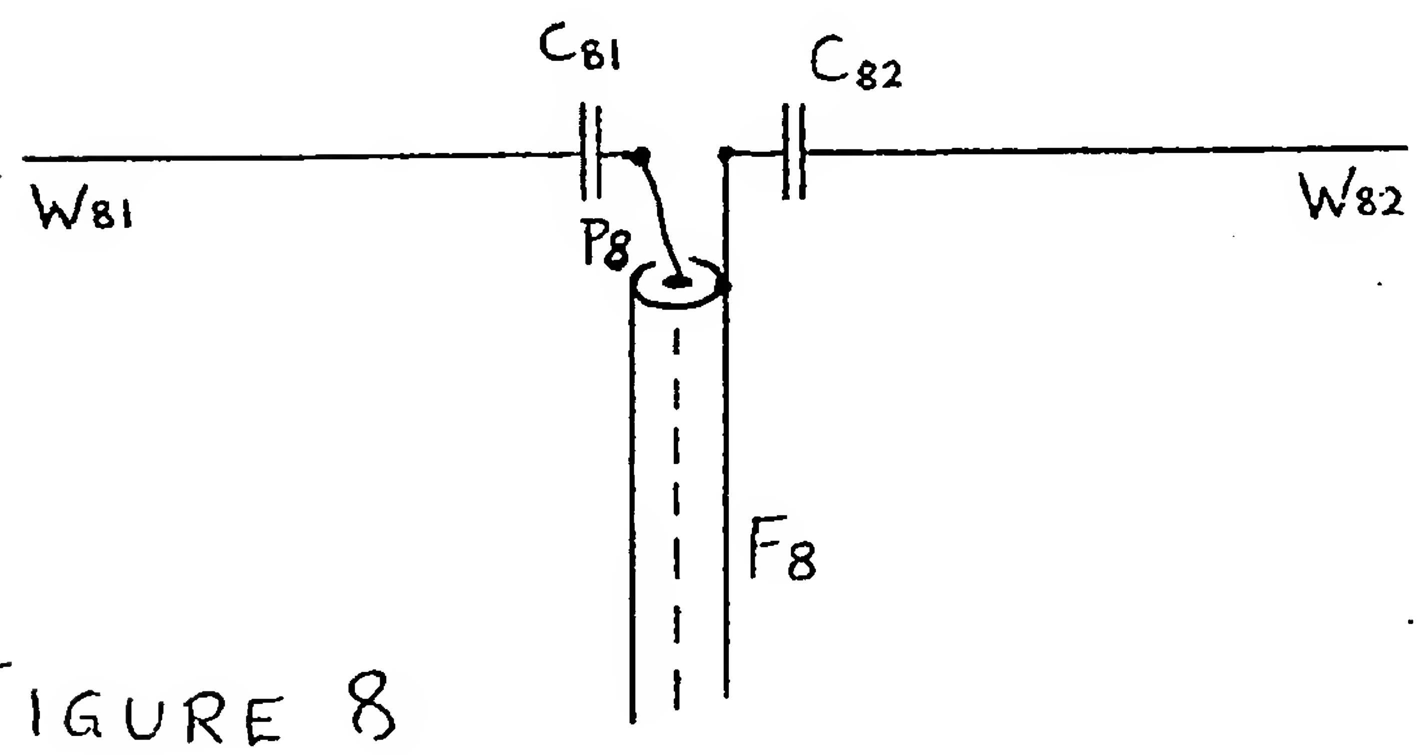

FIGURE 8

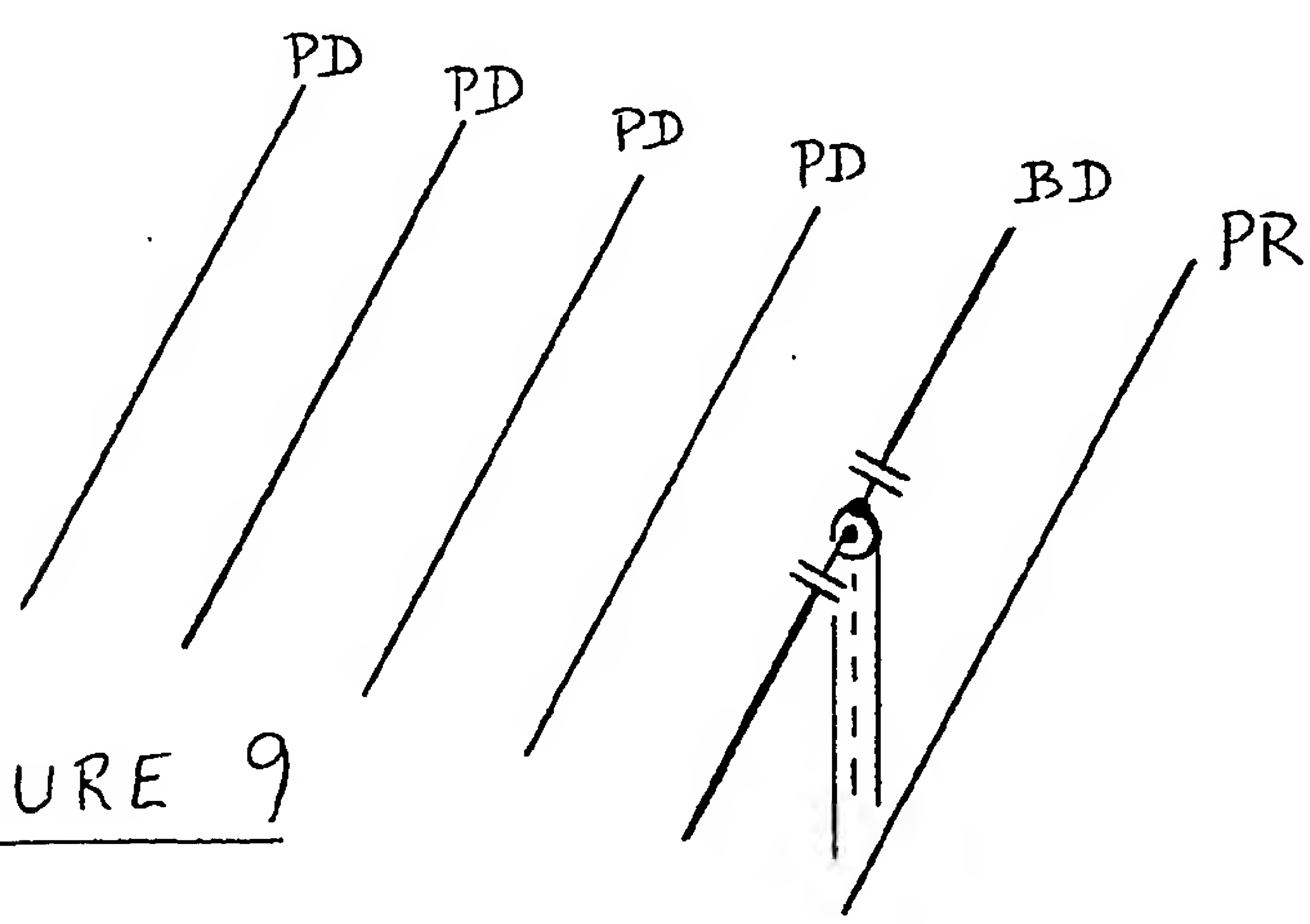

FIGURE 9

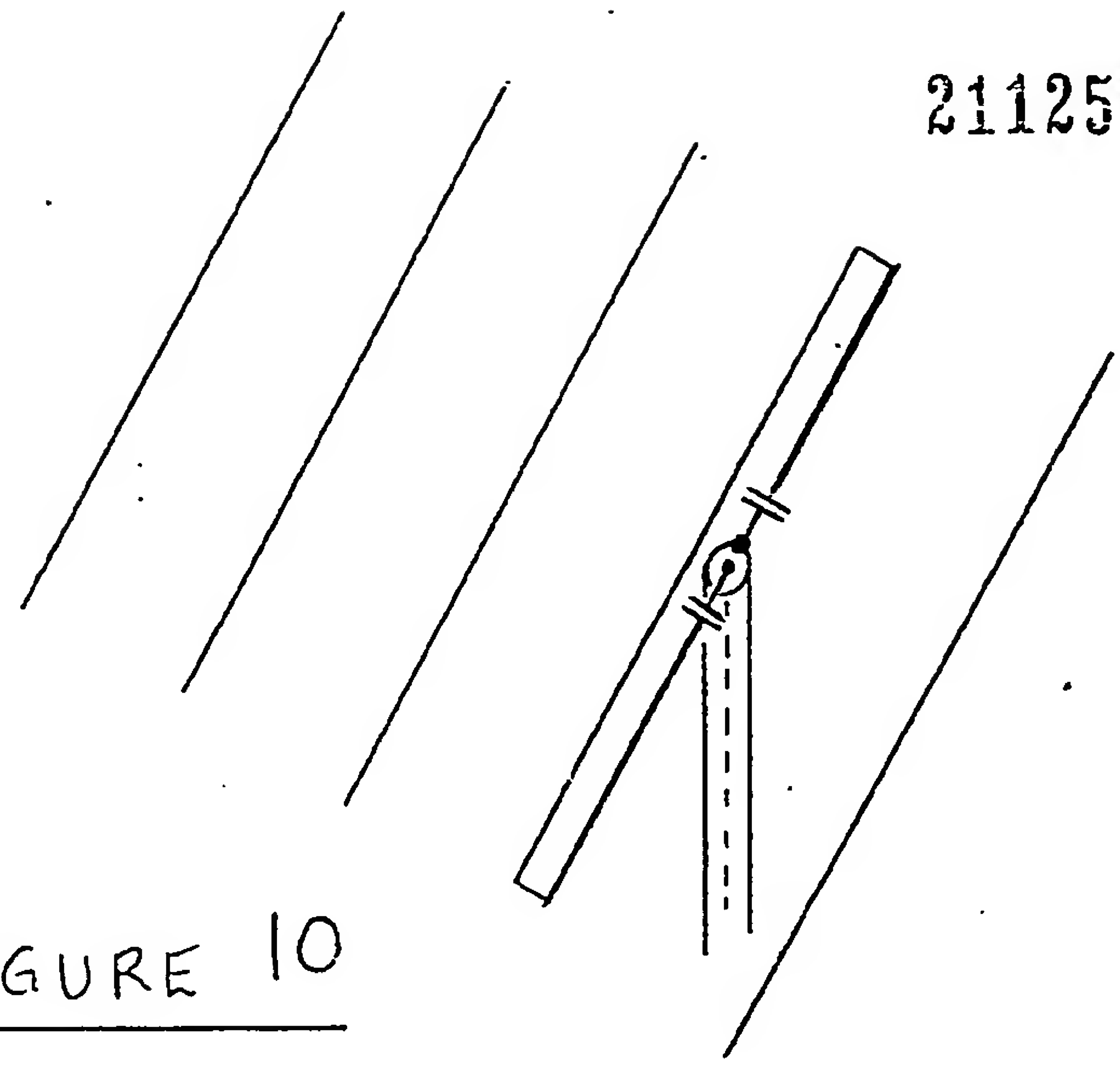

FIGURE 10

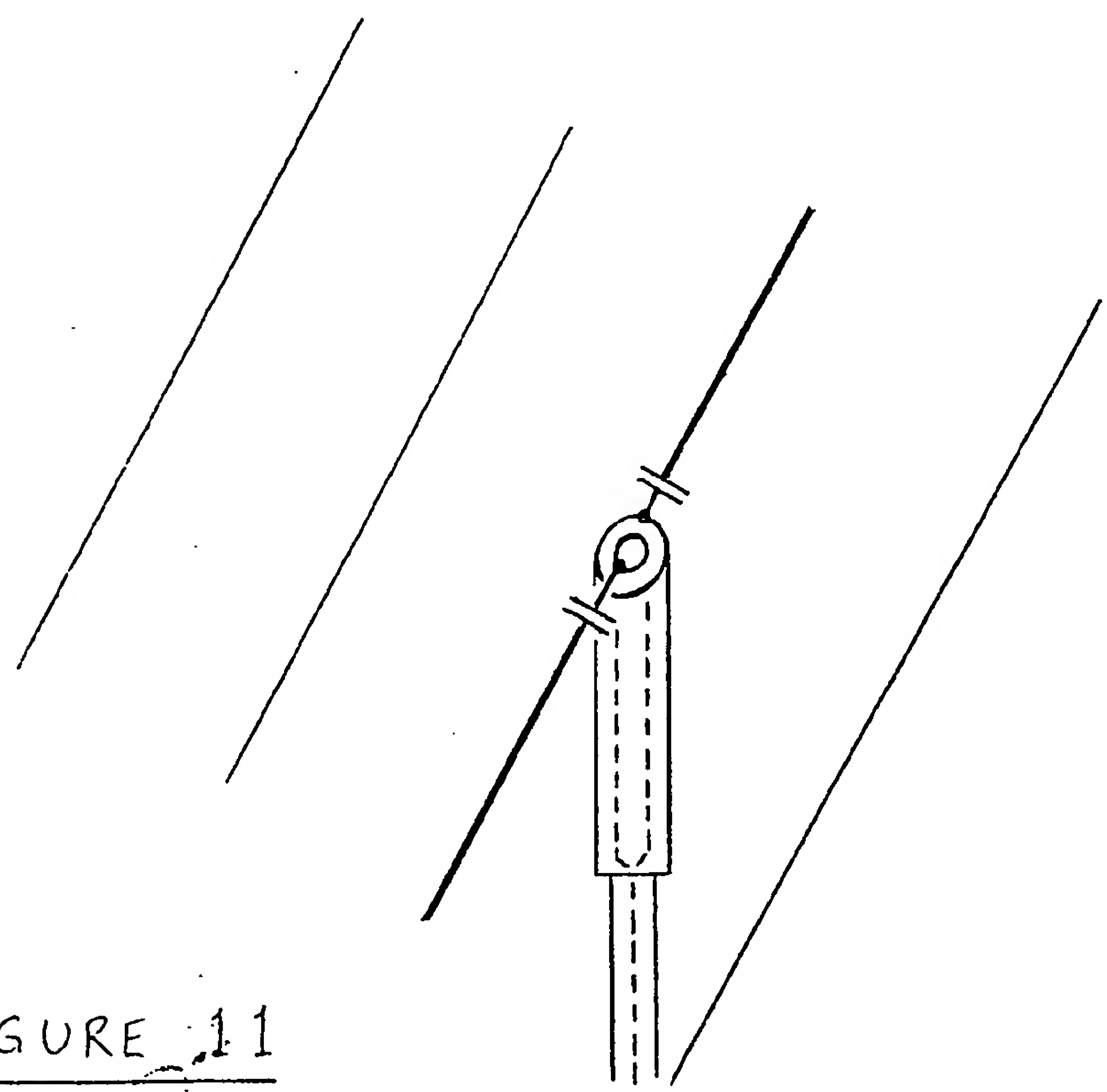

FIGURE 11

SPECIFICATION

Multiband dipoles and ground plane antennas

I, MAURICE CLIFFORD HATELY of 1 Kenfield Place Aberdeen AB1 7UW, British Subject, citizen of the United Kingdom do hereby declare the invention, for which I request that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:–

Antennas used for most of the commercially occupied radio spectrum are either half-wave dipoles or developed forms of the half wave dipole antenna. Such antennas in most previously known systems have been fed in one of two ways. They have been fed using either a balanced feeder or a coaxial feeder. Each system possesses its own severe disadvantage in practice. Balanced feeders which are convenient to engineer are generally high impedance and therefore do not match the impedance of a centre cut in half wave resonant antenna. Coaxial feeders are better matched, but being unbalanced, disturb the field symmetry of balanced antennas such as the half wave dipole and therefore depreciate the protection against local interfering fields afforded by the coaxial construction.

A transmitting antenna may be thought of as a radio frequency energy transformer in which the energy available at the feeder is coupled into space where the said energy radiates as an electromagnetic wave. A receiving antenna is the exact converse of the above and identical considerations apply and so does not require separate analysis. Since the travelling wave impedance of space is 377 ohms, and since most practical radio feeder impedances are in the region of 50 to 150 ohms then the task of antenna design for efficient transformation is one of considerable challenge. Very many designs exist for the layout of the conductor elements, and this disclosure is not intended to add to the number. The disclosure is however concerned with improved feed arrangements usable in most of the presently known antennas but described initially in terms of its use for the most elementary balanced antenna the half-wave dipole.

When stimulated at the appropriate radio frequency a half-wavelength conductor behaves as if it holds standing waves of electric and magnetic fields upon itself due to the establishment of two oppositely travelling waves on the conductor. It has therefore an electrical behaviour equivalent to that of a lumped resonant LC circuit and as such may be operated as a radio frequency transformer.

In order to be efficient, any circuit behaving as a transformer must have small internal losses. A lumped LC circuit in resonance having small losses and significant reactance has a large Q factor. By analogy an efficient radio antenna should be operated in a condition in which it can develop high Q, being a condition in which standing wave phenomena grow to the extent at which the radiation emanating therefrom constitutes the principal energy loss. A good antenna and feed system should allow that resonant currents and voltages are restricted by neither dielectric, magnetic and resistive components in the insulators and conductors nor source impedance at the feed point.

In most previously described antenna feeds the feeder cable has been directly connected within the half wave resonant dipole at a cut in the centre. Presently accepted mathematical analysis indicates that the input impedance at the said cut in a dipole radiating into free space is 73 ohms approximately. In order to prevent reflections on the feeder it has been usual to feed with a nearly matching feeder cable of 75 to 50 ohms characteristic impedance. Laudable as this has been in terms of preventing feeder reflections, it has a considerable disadvantage in limiting the Q factor of the antenna.

Furthermore, since no assymmetry exists electrically in the constitution of an isolated bisected conductor fed by a feeder lying geometrically normal to it, then the centre cut impedance must be a balanced impedance. In spite of this self evident fact, half wave dipole antennas and Yagi-Uda arrays developed therefrom have until now usually been fed by means of a coaxial feeder cable which is, an unbalanced feeder. Not surprisingly the expected benefit of the coaxial feeder i.e. good protection against locally originated interference fields, has not been achieved. Not surprisingly also there are frequently unexplained standing wave problems present. For example in domestic UHF television systems it is normal to find that of the three equal power broadcast channels in the UK, one of the three is weaker than the other two at the coaxial feeder output to the receiver. Similar results occur in reception of VHF FM channels broadcasting high fidelity sound.

Balanced low impedance feeders have been recommended by a few design engineers but have not often been adopted in practice since such feeders when engineered for dipole and Yagi-Uda array matching impedances are dimensionally awkward to manufacture and install.

This disclosure is principally concerned with the problems of coaxially fed antenna balance and radiation efficiency. The arrangements described are also a means by which dipole antennas can be operated on several bands of frequency. Multiband dipoles and their derivative forms can be constructed by the following descriptions. The principles of operation of

these antennas are most easily understood by reference to the multiband dipole. Therefore the description first given will be that of a three band coaxially fed balanced dipole antenna. However the three band antenna is but one example of a multiband coaxially fed balanced dipole antenna. Antennas can be made to operate on five or more bands of frequency. In addition it is of course possible to simiplify the design and a monoband coaxially fed balanced antenna is simultaneously disclosed along with other derivative forms of antenna such as driven arrays partly driven and partly parasitic arrays and finally totally parasitic arrays such as the Yagi-Uda arrays and reflector dish antennas.

Figure 1 shows in idealised diagrammatic form the arrangement of the three band coaxially fed balanced multiband dipole. The bands of frequency are spaced out reasonably for example if the lower frequency is f MHz, the others may be at 1.5f and 2f MHz. Many communications services have allocations over such spacings to enable continuous contact as ionospheric conditions change during the day. The conductor wires W_1 and W_2 are each precisely one quarter of a free space wavelength for the lowest frequency band. They are in close proximity to the other insulated conductor wires W_3 and W_4, and also to W_5 and W_6. Wires W_3 and W_4 are some 7 percent longer than a quarter of a free space wavelength at the middle frequency band. Wires W_5 and W_6 are some 7 percent longer than the free space wavelength of the higher frequency band.

All six capacitors, C_1 C_2 C_3 C_4 C_5 and C_6, are the same magnitude of electrical capacitance. The value may be calculated from the reactance at the lowest band frequency to be radiated which is to be about 3 times the characteristic resistance (R_0) of the coaxial feeder used. Thus $X_c = -j\ 3\ R_0$ ohms at f MHz.

The coaxial F feeder being R_0 ohms in characteristic resistance is connected so that its screen and all the inside plates of the six capacitors constitute a very short common centre connection about which the whole antenna is electrically balanced. The inner conductor of the coaxial cable is connected to the junction between conductor wire W_1 and the left hand plate of capacitor C_1. There are then separate connections between conductor wire W_2 to the right hand plate of C_2, wire W_3 to C_3, wire W_4 to C_4, wire W_5 to C_5 and wire W_6 to C_6 as shown in Fig. 1.

In order to preserve the electrical balance of the multiband dipole the feeder should preferably leave the dipole at right angles to the direction of the conductor wires for the maximum convenient distance, preferably at least one quarter of a wave of the lowest frequency f MHz. The total feeder length may be any desired length thereafter. The disclosed arrangement presenting to the coaxial feeder an input impedance which is close to the characteristic resistance R_0 and substantially resistive over about ± 3 percent either side of the centre frequency of each of three bands. Measurements of voltage standing wave ratio will be found to be 1.3 or less over these frequency ranges.

The magnetic coupling between the insulated wires should be good so that energy may transfer effectively between the fed wire W_1 and the separately resonant half wave dipoles constituted by wire W_3, and W_4 and their respective capacitors C_3 and C_4, and by wires W_5 and W_6 and their respective capacitors C_5 and C_6. The whole group of three wires at each side may be plaited or twisted or run straight according to the best form devised by the designer. However the overall group of wires and capacitors must be preserved from ingress of rainwater for otherwise the characteristic impedance of the group will be changed when wet and excessive loss and bad voltage standing wave behaviour will be observed on the feeder. Find adjustment of the length of the medium and high frequency band quarter wave wires will depend upon the exact moulding form of the group.

The operation of the coaxially fed three band balanced dipole antenna may be explained as follows. Each band is provided with a separately resonant circuit comprising the two conductor wires and respective series capacitors whose total length most nearly corresponds to the half wavelength at that frequency. Since the wires are in close magnetic coupling, the standing wave of current at the lowest frequency band f shares three capacitors at each side and thus sees a capacitive reactance to the centre connector of the dipole of one third of the individual reactances i.e. about $-j\ R_0$ ohms. Similarly the middle frequency standing wave will share two of the centre capacitors each side and will thereby experience a reactance of half of the individual reactances which are themselves proportionally reduced to 0.66 of their former value since the resonant frequency is 1.5f. Thus at the middle band frequency the approximate capacitive reactance is

$$\tfrac{1}{2}\,(0.66 \times 3\ R_0) = -j\ R_0 \text{ ohms}$$

At the higher frequency band 2f MHz, a standing wave exists only on wires W_5 and W_6 and flows only through one pair of capacitors namely C_5 and C_6. At this frequency these have reactances of proportionally reduced magnitude:–

$$\tfrac{1}{2} \times 3\ R_0 = 1.5\ R_0 \text{ ohms}$$

In this manner the three individual standing waves can separately experience similar circuit reactances and have similar equivalent circu-

its. Fig. 2 shows the equivalent balanced half wave dipole which each resonant wire pair resembles. The screen S of the coaxial feeder forming the voltage zero, or earth point, of the balanced system. The two equivalent capacitors C_E shown on the Fig. 3 having at each band a similar reactance magnitude $-j$ (0.9 to 1.6 R_0) ohms. Energy transfer from the feeder inner P is made via the direct connection the left hand quarter wave wire, but because of the phase shift towards 90 degrees advance produced by the capacitor C_E, the travelling waves of current on the resonator are not controlled by the characteristic resistance of the feeder and may therefore rise to larger values than was possible in previously known coaxially fed half wave dipoles. The travelling waves grow until the standing waves they compose develop radiation loss constituting the principal loss of the whole antenna. Transformation efficiency is therefore maximised automatically.

On all bands the capacitors in series with the quarter wave wires not only ensure electrical balance and high efficiency, but also perform a vital role in the transfer of energy from the left hand quarter wave wire to the right hand quarter wave wire. Considering Fig. 3 at the lower frequency band f MHz, some of the current which leaves the inner conductor of the feeder flows on conductor W_{31} and originates a magnetic flux ϕ, around itself and the neighbouring conductors W_{33} and W_{35} induces an electromotive force into these wires which is phased 90 degrees ahead of the magnetic flux. Due to the presence of capacitors C_{33} and C_{35}, the current which flows is approximately 90 degrees of phase ahead of the electromotive force. Thus the currents on wires W_{33} and W_{35} are almost 180 degrees of phase ahead of the antiphase relationship expected between the primary and secondary currents of a magnetically coupled device according to Lenz's law. As a result there is phase coherence between all conductor currents on the left side of the multiband antenna, and the flux ϕ_1 as a partial flux ϕ_2 which by similar considerations draws currents on conductors W_{34} W_{36} and W_{32} all in phase towards the centre point, most of which constitutes the initiating travelling wave on the resonant quarter wave wires W_{31} and W_{32} and some of which constitutes current down the feeder screen to replace the initial feeder inner conductor current with which the considerations commenced. Flux re-inforcement, occurs on this side also. By this means a standing wave current may be established on conductors W_{31} and W_{32} considerably phase advanced on and much larger than the initiating feeder current flowing from P and back into S.

Exactly analogous considerations explain the operation of the antenna at the middle frequency band, and at the higher frequency band. Of course wires W_{31} and W_{32} in these cases constitute initiating conductors only, the standing waves of large amplitude being confined to one or other pair of quarter wave wires only as wave travel time and wave frequency determine.

Multiband antennas which will operate on five or more bands may be constructed using the same design formula, i.e. all capacitors being identical and having a reactance at the lowest frequency of $-j\ 3\ R_0$ and frequency bands having a reasonable separation such as f, 1.5f, 2f, 4f, 6f or f, 2f, 4f, 6f, 8f etc. The current sharing phenomenon at the centre capacitors approximating towards the desired condition in a benign manner in most cases. Fig. 4 shows a five band antenna for example.

The lengths of the shorter individual wires are cut be some 5 to 10 percent more than the free space quarter wavelength at each frequency band to be radiated, depending upon wire diameter, insulation dielectric and bundle spacing. The need for excess length is accounted for in theory by the paralleled inductance behaviour of the coherent phase of currents in the wires of the bundle, the longest wire not experiencing the effect near its extremities is of course an exact quarter wavelength. Following this description it is now possible to explain the operation of the single band form of the above antenna.

The design of the coaxially fed balanced monoband dipole is described with reference to Fig. 5. The wires W_{57} and W_{58} are each exactly a free space quarter wavelength, and the third wire W_{59} in close proximity but insulated from W_{57} is approximately $1/\sqrt{2}$ times the free space quarter wavelength. Capacitors C_{52} and C_{53} constitute the electrical balance and phase shift capacitors incorporated within the previously described multiband antennas. Capacitor C_{51} may or may not be present since the transmission line effect of W_{53} and W_{51} together for 0.707 of a quarter wavelength presents a large capacitive susceptance across the capacitor C_{51} whether it is present or not. Capacitors C_{52} and C_{53} are identical and should each have a reactance of $-j\ R_0/\sqrt{2}$ ohms at the frequency of operation. Energy transfer from W_{57} to W_{58} is accomplished via induction into W_{59} in a manner similar to the previously described multiband form of coaxially fed balanced antenna.

Developing again a more complex antenna, if desired for reasons of materials economy or weight reduction etc, a multiband form of the previous monoband antenna may be constructed in the manner shown in Fig. 6. The conductor wires W_{61} W_{63} W_{65} constitute the quarter wavelength resonant sections, and the single counterbalance wire W_{62} carries the counterpoise currents at any of the resonant frequencies. Capacitors C_{63} and C_{65} are identical and are designed to be such as to have a

reactance at the lowest frequency band of $-j\ 3\ R_0$ ohms. Capacitor C_{62} is approximately one third of the magnitude of reactance being $-j\ R_0$ ohms. Capacitor C_{61} may be either equal to C_{63} and C_{65} or absent.

Extension of the above concept leads to the coaxially fed multiband ground plane antenna which by way of example is shown in a three band version in Fig. 7. The screen of the feeder is connected at the centre of a wide sheet, or an effective metal conducting sheet composed of a mesh of metal or an array of radially disposed conductors, in width at least half a free space wavelength at the lowest operating frequency. The inner conductor of the coaxial feeder is connected to the largest perpendicular radiator conductor W_{61} which is an approximate free space quarter wavelength or some greater wavelength at the lowest operating frequency band. Two conductors W_{72} and W_{73} constituting resonators at the other two operating frequency bands of this example are fixed in close proximity to but insulated from W_{71} and are separately connected by their respective phase shifting capacitors C_{73} and C_{75} which are identical in magnitude having a reactance of $-j\ 3\ R_0$ ohms each at the lowest frequency band.

The lengths of the middle and higher frequency resonators will be a few percent larger than the free space quarter wavelength for the band to be radiated. More than three bands of operation can be achieved provided there is sufficient frequency spacing between the said bands. If desired to construct a directional multiband ground plane antenna, further resonators may be placed in the vicinity of the desired directions according to the director of reflector spacing arrangements commonly adopted in the analogous Yagi-Uda parasitic arrays.

The coaxially fed balanced monoband dipole feed antenna of Fig. 5 may be simplified further to the arrangement shown in Fig. 8. The wires W_{81} and W_{82} are both a free space quarter wavelength, or a few percent less depending upon the proximity of other objects in the antenna environment. Capacitors C_{81} and C_{82} are both identical capacitance values such as to have a reactance of $-j\ R_0/\sqrt{2}$ ohms at the frequency of operation. The placement of capacitor C_{81} in series with the feeder connection P_8 allows the correct phase shift of standing wave to be developed on the two quarter wave sections, so that proper balance is maintained over a reasonable percentage band of operation of this dipole.

In all forms of the coaxially fed balanced dipole described, the choice of capacitor type, and conductor wire insulation must be decided having regard to dielectric loss ratings expected. When incorporated into Yagi-Uda arrays of the parasitic type, the coaxially fed balanced dipole (BD) whether monoband as shown in Fig. 9 with parasitic reflector (PR) and directors (PD), or a multiband form, no shown, a considerable reduction in the impedance presented to the coaxial feeder will occur. The problem may be overcome by any of the standard techniques. For monoband antenna, a closely spaced half wavelength element may be fixed in close proximity, or connected across the ends of the antenna in the manner of a folded dipole. Alternatively a short piece of low impedance coaxial feeder may be inserted between the centre of the antenna and the main coaxial feeder, cut to a length appropriate to transform the impedance up to the feeder impedance. For a multiband antenna, a ferrite cored transformer will be necessary.

CLAIMS

1. A circuit for use in radio antenna construction comprising an even number of insulated capacitors of such a capacitance that they each cause phase shift of several tens of degrees between voltage and current at the frequency bands of operation and connected in series pairs at the centre of pairs of insulated conductor wires whose several number can all be separately stimulated in pairs to carry on one pair a standing wave of radio frequency so that radio energy radiation may take place at each one of several frequency bands when excited by energy of the said frequency on an unbalanced coaxial feeder connected with its screen to the centre of all said series pairs of capacitors and with the inner conductor of said feeder connected to one of the wires of the longest pair at the point at which said wire is connected to its associated capacitor.

2. A circuit of the general type of claim (1) reduced in complexity and consisting of a single pair of phase shifting capacitors in series at the centre of a single pair of conductor wires which are of such at length that the pair can be excited to carry a standing wave at one band of frequency and thereby radiate at said frequency band and which incorporates an energy transfer and balance circuit consisting of a third insulated conductor whose length is more than one eighth of a wavelength placed in close proximity to the wire of said pair which is directly connected to the inner of the unbalanced feeder cable and from said third wire is connected a third phase shifting capacitor to the centre connection of said pair of capacitors and to which said centre connection the unbalanced coaxial feeder cable screen is connected.

3. A circuit of the type of claim (2) which has been further simplified and consists of two conductor wires and two phase shifting capacitors only, one of which is connected between the inner of the unbalanced coaxial feeder cable and one of said conductor wires and the other capacitor is connected between the screen of the said feeder and the second

said conductor wire, which by reason of the phase shift so engendered and the approximate total length of the conductor wires within the whole system develops a standing wave at one frequency band.

4. An unbalanced form of antenna from claim (1) in which the screen of the coaxial feeder is connected to the centre of a wide metal sheet, or effective conducting sheet composed of a metallic mesh, or composed of an array of conductor wires radially disposed, extending to at least one free space quarter wavelength of the lowest frequency to be radiated and having the inner conductor of said conductor connected either directly to a free-space quarter wavelength conductor perpendicular to said sheet and to a phase shifting capacitor connected thereto and to the said sheet or in series with a phase shifting capacitor to a quarter wavelength conductor perpendicular to said sheet and otherwise insulated, and the said antenna having one or more additional conductor and series connected phase shifting capacitor groups each capable of being excited as a quarter wave resonator and thereby radiating at one of several frequency bands.

5. An antenna of any of form described under claims (1) to (4) inclusive which is mounted in any form of array of additional elements whether driven, or parasitically excited, or focussed by a dish reflector.

Printed for Her Majesty's Stationery Office
by Burgess & Son (Abingdon) Ltd.—1983.
Published at The Patent Office, 25 Southampton Buildings,
London, WC2A 1AY, from which copies may be obtained.